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Archaeology and Augmented Reality. Visualizing Stone Age Sea Level on Location

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Abstract
When interpreting and disseminating the localisation of Stone Age sites along the rugged coast of Norway, it is always pertinent to include knowledge about sea level at the time the various sites were in use. This is important for archaeological surveying and excavation, as well as mediation to the public at large. When one finds oneself on a Stone Age site a kilometre inland and in the thick of a dark forest, it is not easy to imagine what the place actually looked like six thousand years earlier when the site was in use by Neolithic people, and was part of a coastline exposed to the open sea. How can we take advantage of the current state-of-the-art in location-based media and mobile augmented reality in order to bring dynamic visualizations of the ancient landscape into the hands of both archaeologists and interested visitors? In this article, we report on the development and testing of a situated simulation where the user can move around in a given landscape and view a parallel simulation of the sea level from pre-historic times up to the present on a smartphone or tablet. The application uses an indirect augmented reality solution and the sea level/time-period can be altered continuously. When approaching a surveyed and/or excavated site, one can also observe its extent and via spatially positioned hypertext links, access the online databases for multimodal information about the findings. The prototype runs on iOS and has been tested with a small group of visitors on location. The article concludes with a discussion of the user evaluation and suggestions for further work.

Keywords: visualisation, situated simulation, mobile augmented reality, land rise, Norway

Introduction

Anyone familiar with archaeology in the field knows how challenging it might be to imagine how a particular location may have appeared in prehistoric times, in particular given changes in vegetation and sea level. This may not be insurmountable for the individual surveyor searching for relics or traces of ancient and historical culture; with experience the field archaeologists will cultivate adequate judgemental powers in order to distinguish the look of the present surrounding from its many past variations. However, for the untrained eye of the layperson, such changes may be very difficult and challenging to comprehend. How may we employ recent developments in mobile digital technology to solve some of the visualizing challenges in these on site situations? Mobile augmented reality solutions have, for quite some time, been developed for use on cultural heritage sites (Vlahakis *et al*., 2000; Tscheu and Buhallis, 2016) and suggested and tested for various aspects related to archaeological fieldwork (Mohammed-Amin *et al*., 2012; Deliyiannis and Papaioannou, 2014; Liestøl and Rasmussen, 2010). However, such systems have primarily been focused on the archaeological reconstructions rather than the surrounding area, such as the larger natural environment including change in sea level and vegetation.

In the project reported here, we have deployed a platform for publishing situated simulations, a kind of Indirect Augmented Reality (Wither *et al*., 2011), which has been in development since 2008, and applied to a variety of cultural heritage sites as well as simulations representing climate change (Liestøl *et al*., 2014). In a situated simulation (sitsim) the user's visual perception of the real physical environment is coupled with the user's visual perception of a 3D graphics environment as displayed on a hand-held screen. The relative congruity between the real and the virtual perspectives is obtained by letting the camera position and movement in the 3D environment be conditioned by the positioning, movement and orientation hardware. As the user moves in real space, the perspective inside the 3D graphic environment changes accordingly in

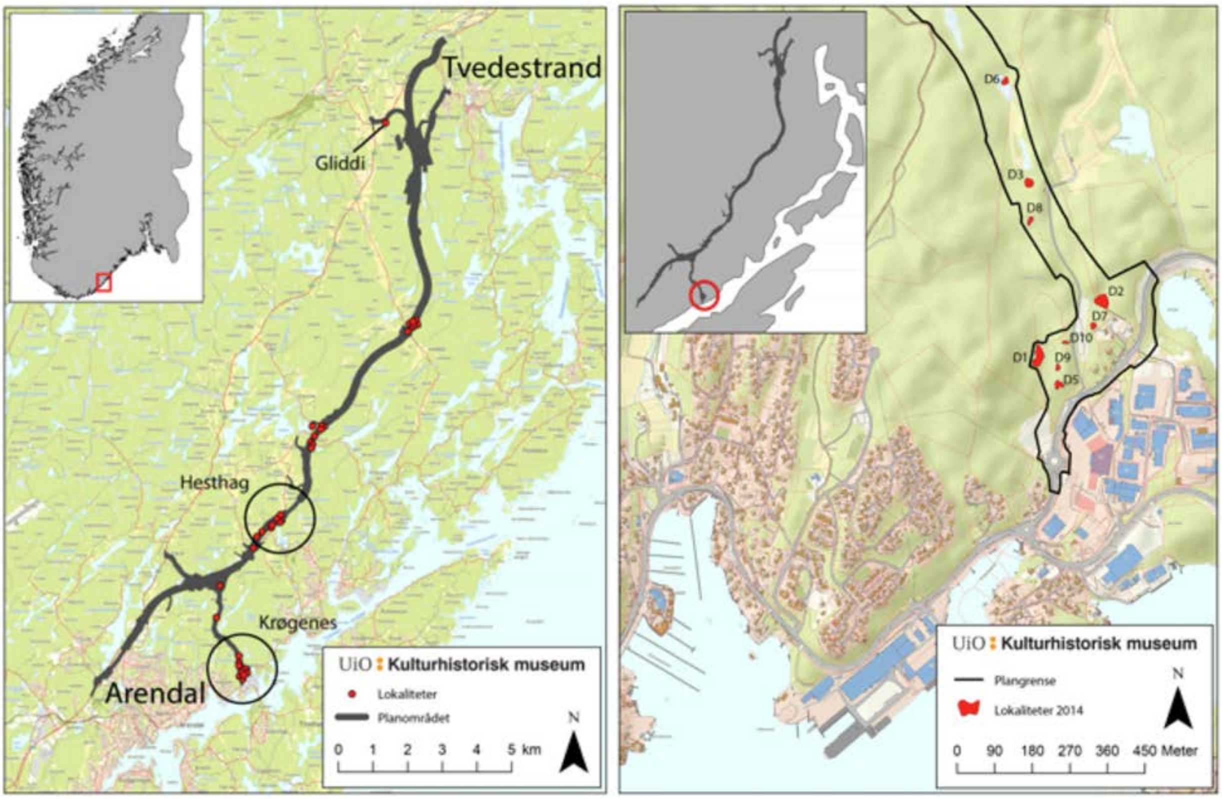

Figure 1. Location of the Krøgenes sites.

real time. The system also includes spatially distributed hypertext links for access to various kinds of additional information and different 'views' (zoom, bird's view etc.) for improved orientation and observation (Liestøl and Morrison, 2013), for more information see the projects web site at www.sitsim.no.

The main purpose of the experiment reported here was to create a dynamic, digital 3D environment for continuous display of changes in sea level and vegetation. At the same time, it includes the location of the excavated Stone Age sites in the area and allows access to the online archaeological databases of findings based on the excavations. In the following we first describe the archaeological area in question and the excavations; then we present the digital field museum and its databases, which can be accessed on location. Further, we describe the programming architecture as well as the graphical solutions, before finally presenting the test and evaluation with a small group of users on location. We conclude with some suggestions for further work.

The Krøgenes sites and excavations

On the southern–most coastline of Norway, between Tvedestrand and Arendal, 38 archaeological sites were excavated in the period 2014–2016 due to the building of the new E-18 motorway in the area. The new road is about 2–3 km from the present coastline, and the landscape is hilly with small fjords.

In the Stone Age, the landscape was rather different, with higher sea levels than today due to the isostatic land rise after the Ice Age. Based on the landscape formations, the archaeological localities are interpreted as coast-bound sites. Consequently, the oldest are situated highest in the landscape, and the youngest further down. The Stone Age people lived predominantly very close to the sea. The area chosen for the sitsim presented here is called *Krøgenes*. It is located on the north–western side of Tromøy and the city of Arendal. Nine settlements were excavated here in 2014. These sites are located from 14–58 m a.s.l., dating from the Middle Mesolithic to the Middle Neolithic periods. There are also several quartz quarries in the area, which have been in use from the Stone Age up to modern times.

The area as a whole may have looked quite similar in the Stone Age, as the landscape appears today, with small fjords, archipelagos and small islands providing good protection from the open sea. This is one of the main reasons for choosing it for modelling a prehistoric landscape, together with archaeological results based on excavated localities placed at different sea

Figure 2. Krøgenes D2-

Figure 3. Krøgenes D7 and Krøgenes D10.

levels. The different heights of settlements in a small area like this also provides a unique potential to see connections, similarities and differences between them as the sea level and vegetation change over time. In the sitsim, three different settlements were chosen as representative for the Krøgenes area:

Krøgenes D2 (22 m a.s.l.) showed a massive cultural layer, and axe production. The settlement is situated in a natural amphi, and is dated to the Late Mesolithic period. The site has around 23,000 finds of flint, quartz and local stone used for the axe production.

Krøgenes D7 (19 m a.s.l.) is a small single-phase settlement from the Early Neolithic period. The majority of the finds are flint debitage from the reduction of flint cores.

Krøgenes D10 (19 m a.s.l.) is located opposite D7 on the other side of a prehistoric inlet, and also from the Early Neolithic. The finds were quite similar, except from a small area with 4200 pieces of processed quartz, which probably represents a single event at the site.

Connecting to the *Digital Field Museum*

The sitsim was developed as part of the *Digital Field Museum* project. Excavations always create interest locally, but too often an excavation and the subsequent curating of the finds are separate events. *Digital Field Museum* was started to bring excavations and museum collections closer and to create more understanding of the links between the knowledge of prehistory, the exhibitions and the excavations. This will be achieved by bringing the collections out to the excavation site and the excavations into the museum. In 2015, two parts of this project were carried out. One was an event at the museum where school classes were online with one of the E18 excavation sites. The archaeologists in Tvedestrand used mobile devices to guide around the excavation site and to answer questions, and the students were quite enthusiastic about being online and communicating with the archaeologists. The other task in 2015 was to develop the sitsim-application presented here, which would increase the understanding of the paleo-environment at the site and also be a starting point for an investigation of the collections and documentation at the Museum of Cultural History at the University of Oslo.

The Museum of Cultural History is responsible for all prehistoric excavations in the ten eastern and southern most counties in Norway. The excavation documentation is now born digital, and earlier catalogues and photo documentation have been digitised. As a result, the collections are available online, and all new acquisitions are catalogued in the national database systems for the university museums and published at www.unimus.no. All of the archaeological collections at the university museums in Norway use the same net portal, and as of August 2016, close to one million entries are published. The artefact catalogues are geotagged and this and other metadata can be freely downloaded. Photographs from excavations and of artefacts are published with CC—licence (Matsumoto and Uleberg, 2015). Excavation reports are now published at http://www.duo.uio.no, which is the Open Research Archive at the University of Oslo. So far more than 100 excavation reports have been published. All in all, there are large amounts of data waiting to be used in different applications.

Programming challenges and architecture

With the release of the iPhone in 2007 and the iPhone SDK in 2008, mobile computing became reality. The development of sitsim-applications started in the fall of 2008 and has since the start primarily been based on the iOS platform and Unity game engine. With a game engine supporting multiple platforms, some applications have also been adapted to the Android platform. Over the years, technical advancements in mobile devices have resulted in better performance, graphics capabilities, and new and more accurate sensors. Although the applications have been developed continuously and benefit hugely from these advancements, there are still challenges, mainly regarding the limited performance of mobile devices. Because of these limitations, there will always be a need for simplifications, in models, graphics, accuracy etc. These simplifications have to be carefully weighted and implemented with each individual application in order to not affect their main purposes and key values.

With a sitsim application being a kind of augmented reality application, the user is moving around and pointing the device in different directions instead of using ordinary game controllers with sticks and buttons to control the perspective. One can see the device as a window into the past (or the future) instead of the current reality, and exploring the application is as simple as using a point-and-shoot camera. Sitsim applications usually cover a very large area (often more than 10,000s of square meters) and the use of visual (fiducial) markers (which is nearly standard in most mixed and augmented reality applications) is impossible. Instead, the application is relying on the device's own sensors only when aligning the perspective of the simulated 3D graphics environment with that of the physical reality. The GPS is used to acquire the user's position, down to an accuracy of three meters,

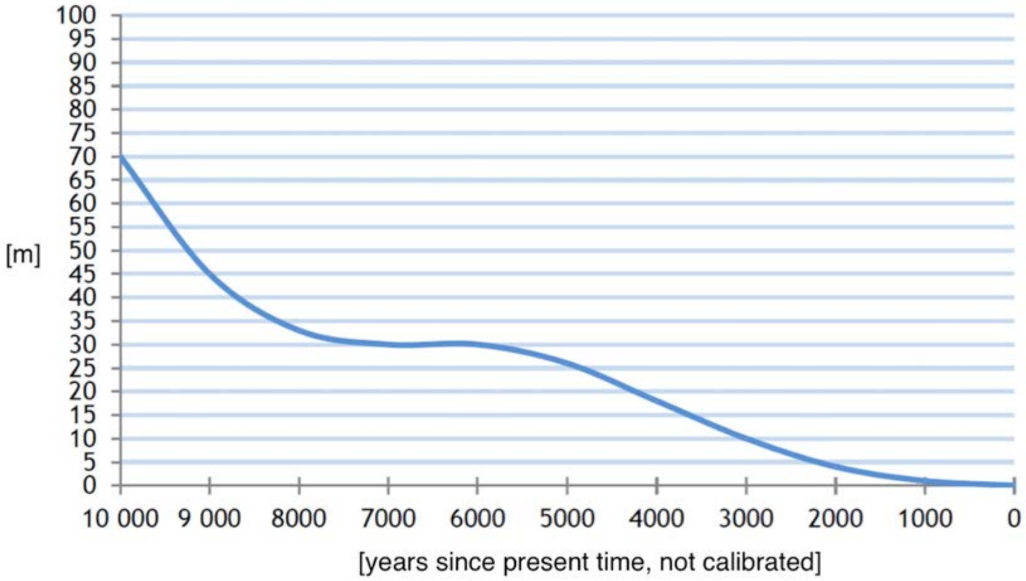

Figure 4. Changes in sea level over time (after Andersen, 1976).

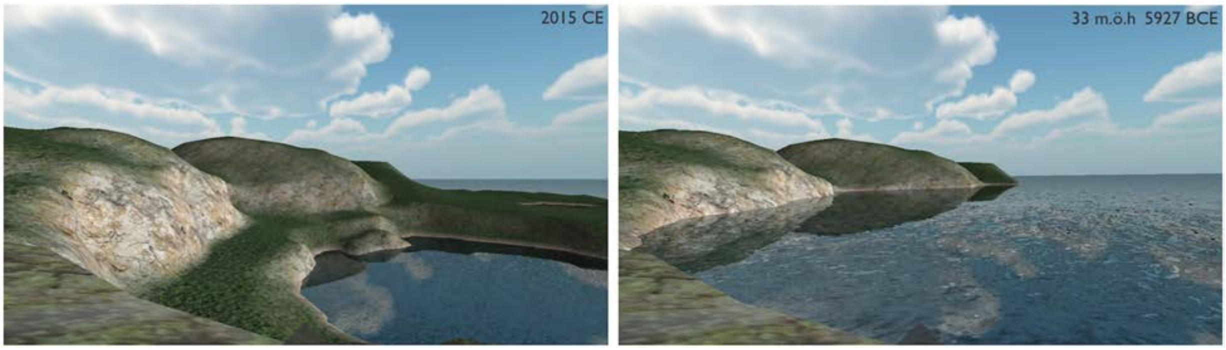

Figure 5. Changes in sea level: 2015 AD versus 5927 BC (screenshot from the Krøgenes prototype).

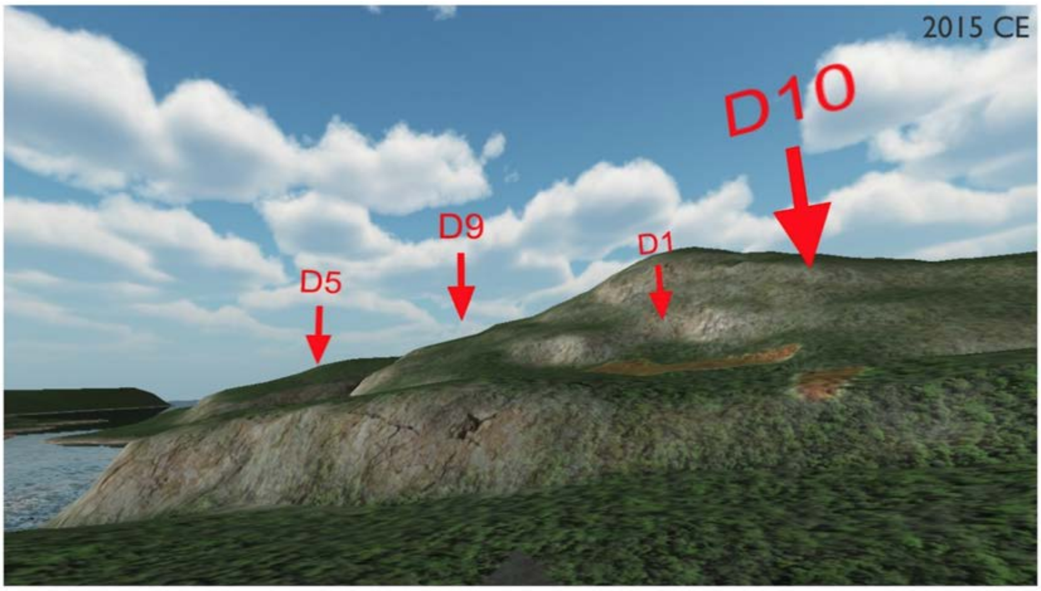

Figure 6. Marking the stonage sites in the terrain.

depending on the surroundings and current weather. In order to track the device's orientation, both in short term (fast rotations in fractions of a second) and long term (stay calibrated over time), the output from the compass, accelerometer and gyroscope is fed through a calibrated filter to calculate the orientation of the artificial camera in the application. The only tools used to create the sitsim application (excluding tools used for graphical content such as 3D models and textures) are Unity (user facing functionality and 3D graphics visualisation) and Xcode (access to sensors and other device specific functionality).

The ambition of this project has not been to create a photorealistic representation of the actual sites, but to capture the changes of the shore line with post-glacial rebound and how that maps with known settlements in the area of interest.

The prototype is modelled on two basic assumptions regarding the area: a) it's mainly covered with a homogenous vegetation, regardless of altitude and timeframe; b) the post-glacial rebound is uniform and the elevation profile is unaffected over time. In order to achieve a more visually realistic and appealing presentation, the vegetation is also assumed to be sparse in steep terrain and close to the shoreline.

For technical simplicity, only three different vegetation/terrain types were used to visualize the terrain: a) Forest: Dense forest with medium sized trees and large bushes; b) Grass, moss and lichen: Rock partly covered with grass, moss and lichen; and c) Rock: Bare rock. The vegetation types were visually presented by applying different alpha textures to the terrain, no 3D-models of trees or shrubs are used in the current prototype.

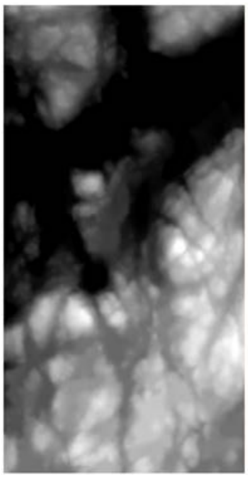

Figure 7. Height map.

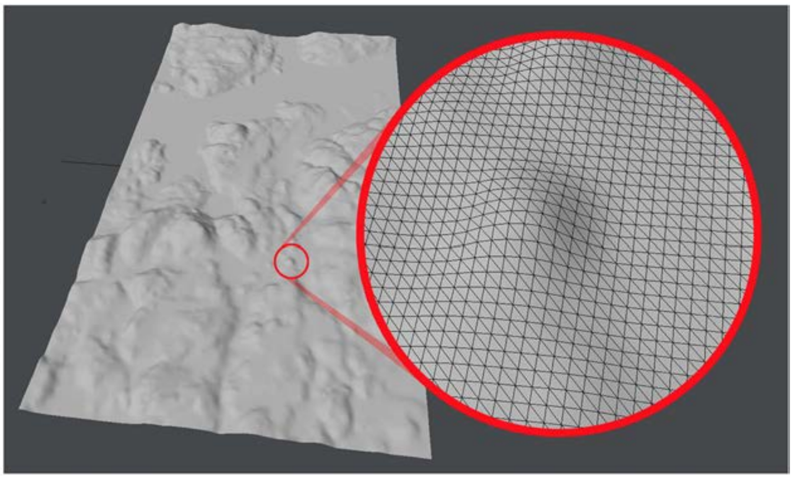

Figure 8. The resulting 3D mesh.

The altitude above sea level and the inclination of the terrain are used as input values when calculating the visibility of each vegetation type. The final result is achieved by calculating the resulting terrain texture in two steps: 1) starting at sea level and moving upwards, grass, moss and lichen gradually changes from full visibility to transparency at the same time as forest changes from full transparency to visibility; 2) the visibility of the result from the previous calculation is modified depending on the slope-in vertical terrain it is fully transparent and only rock is visible, as the terrain gets less steep it gradually gets more visible and finally covers the rock completely.

In the prototype, the user can control the timeframe using a slider ranging from 8300 BCE to present time. The modelled rebound is based on Andersen (1976), see Figure 4. For simplicity of implementation, the sea level is increased as the user moves the slider back in time, instead of lowering the terrain into the sea, the visual appearance and end result is the same. Figure 5 above illustrates the difference in sea level (actually rebound); the sea level around 6000 BCE was approximately 33 m higher than it is today.

To help the user find the interesting settlements, it is possible to activate a highlighting function. By activating this, big arrows will be presented above the sites, and the area of the archaeological locations are highlighted by projecting a signature colour directly on the terrain (see Figure 6).

Graphical solutions

Real-time rendering presents major limitations, because all elements that are visible on the screen have to be processed and rendered extremely fast (dozens of times per second). This means that visual elements directly impact performance and feasibility of the simulation, and need to be optimised and prepared for this specific usage. It is also important to note that modern mobile devices are able to handle rather large amounts of geometry and other visual information, but it is still quite easy to exceed the supported limits if one is not careful.

The main characteristic of the 3D terrain model that can be adapted and optimised is the level of detail: in particular polygon and vertex count. Since the terrain model is a continuous, triangulated, smooth mesh, the vertex count and polygon (triangle) count are directly related. For this reason, we will only talk about the polygon count and refer to the number of triangles.

The Krøgenes terrain was created in two stages. During the first stage, less detailed information of the terrain was obtained in a DEM (Digital Elevation Model) file format, which is the usual format to store elevation data of the Earth's surface and all objects on top of it. This file format contains height information and therefore it can be exported as a black and white image (a height map), where black represents the lowest point of the terrain and white represents the highest one. This black and white image can then be used to create a 3D mesh. Now, to convert the image to a 3D mesh, a flat and very detailed uniformly distributed mesh is created first. The height map is then used to displace the mesh according to the brightness of each area in the image, creating the 3D shape of the terrain. Figure 7 shows the height map and Figure 8 the resulting 3D mesh. The mesh was then optimised (discussed in detail below). For the creation of the 3D mesh we could use almost any 3D program that is used for 3D polygonal modelling, since the necessary steps can be reproduced

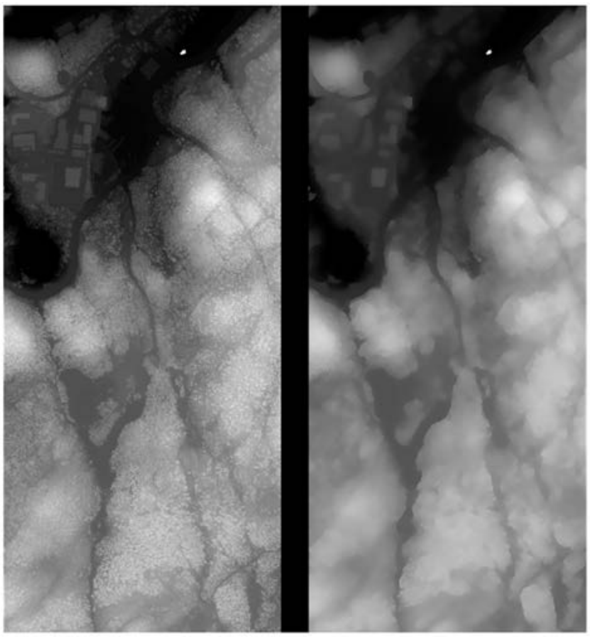

Figure 9. Removing noise caused by vegetation.

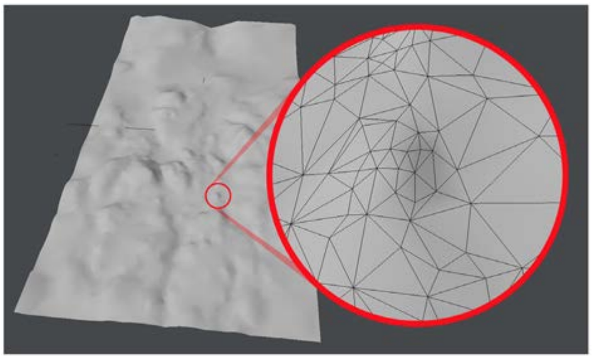

Figure 10. Optimized initial mesh.

in most of those programs. However, Lightwave3D was chosen, because it was familiar and we were well aware of its capabilities.

The second stage was entered when a much more detailed height map was obtained for the main area of the terrain. A very similar process was followed, but there was one additional step: the new height map was so detailed that it included vegetation height, which looked like noise for the most part. Because of this, the height map had to be smoothed out to remove the minor details, but keep the essential shapes of the terrain. A Photoshop filter called 'Surface Blur' was used for smoothing by applying it multiple times with different sets of parameters. What this filter does is blur areas where the local contrast is low, which means that small unnecessary details are removed, whereas greater differences in height are not affected. The initial and the resulting images can be seen in Figure 9.

After transforming the new height map to a 3D mesh, it had to be integrated into the initial mesh. Since it only covered a part of the necessary area, that area had to be cut out from the initial mesh and the new mesh had to be manually inserted and connected into the newly created opening. The resulting mesh was also optimised to reduce the polygon count.

The terrain is a natural object and therefore has an irregular shape. This means that some parts are more detailed than the others, which allows us to optimise some parts more by keeping more polygons on the detailed areas. In addition, the important areas of the simulation are predefined, and the user will not be able to see other areas close up, so we can use more polygons on the important areas at the expense of

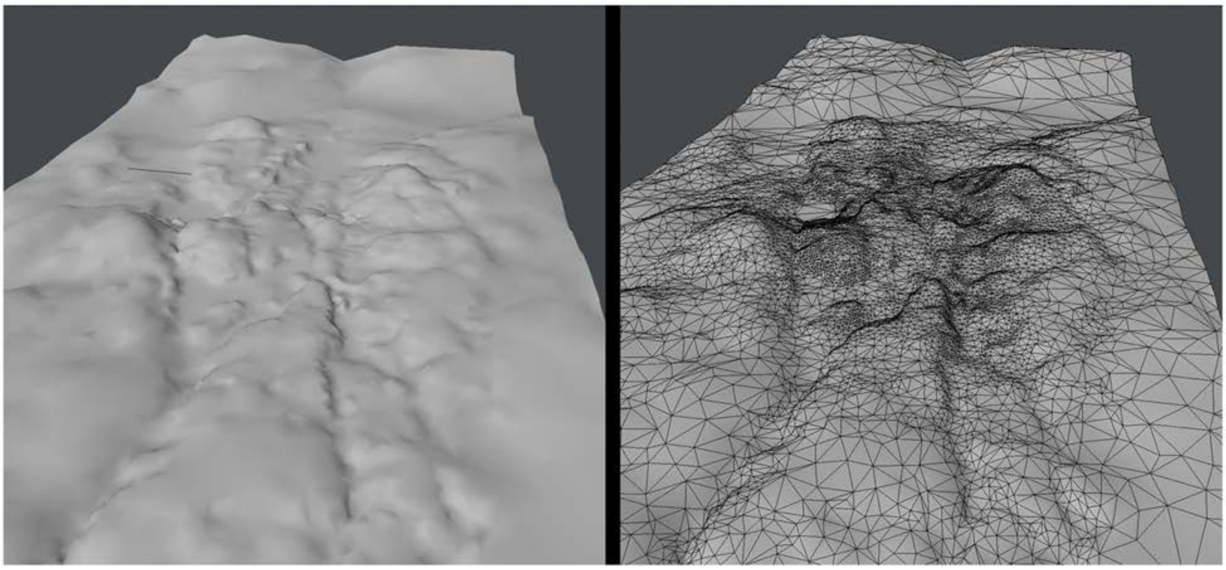

Figure 11. Resulting terrain model, wireframe mode to the right.

Figure 12. Users with iPad and the Krøgenes sitsim activated on location. Experience has shown that it is advantageous to tilt the artificial camera about 15% (photo on the right). This is done to avoid the screen from blocking the real view of the surroundings. In actual use there is no problem combining the two perspectives. On photo and video, however, the vertical displacement looks rather confusing.

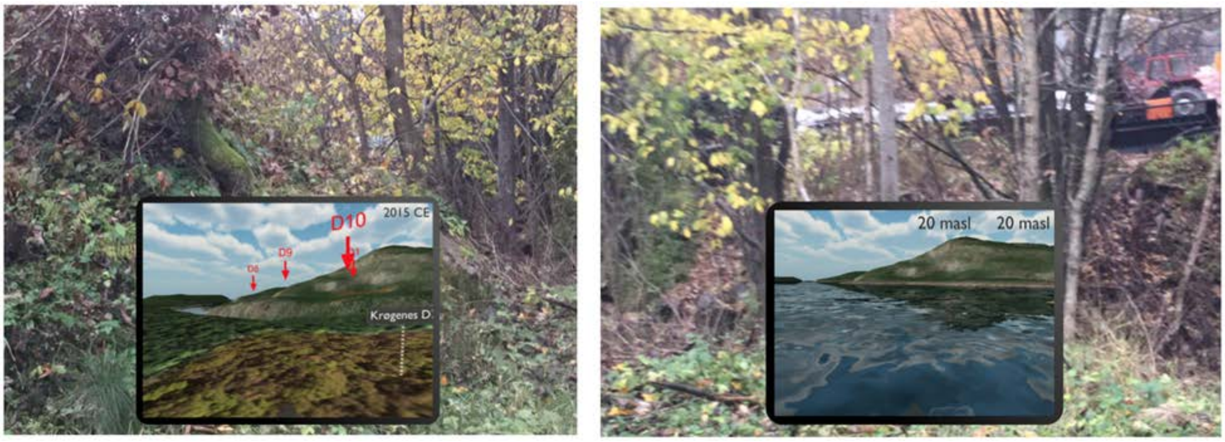

Figure 13. Two illustrations using the now/then photo montage feature in the app. A picture is taken with the real and the artificial camera at the same time. In this case the 15% tilting of the artificial camera is not operational (as in Figure 12). Both images are produced on location D2 looking south west. In the illustration to the left the sea level is set to present time and the feature to show the position of other stone age sites nearby is active (red arrows). Visible in the virtual perspective (frame) is also the hypertext link to the online database. In the illustration to the right, produced from almost the same position, but oriented more to the right (west), the sea level is set to 20 meters above current level and thus flooding the lower parts of the site.

the ones further away. Having these factors in mind, we can use a semi-automatic mesh optimisation tool that takes into account a predefined importance map (to specify the important areas) and the shape of the mesh in specific areas. In this particular case a third-party Lightwave3D plug-in called 'PLG Simplify Mesh' was used, outlining automatic mesh simplification techniques (Hoppe, 1999; Zelinka and Garland, 2002). The overall optimisation is performed in three major steps:

1. Optimise the polygon count by reducing it on the areas with simpler shapes (other areas are usually also reduced, but less).
2. Assign the importance map to the terrain and optimise the further areas even more.

3. Manually fix the issues that are presented by the automatic calculations on the mesh (skewed polygons, random sharp edges, etc.).

The optimised initial mesh can be seen in Figure 10. The shape of the terrain is still similar to the one in Figure 8, but the mesh itself is more irregular and has far fewer polygons. The same optimisation process was applied to the mesh that was created from the more detailed height map, and the resulting terrain model is shown in Figure 11. The wire-frame (black lines) on the right side indicates the edges of the polygons, so the differences between the levels of details can be clearly recognised from the illustration: the main area of the terrain is much more detailed than the outer areas, and the flatter areas are sparse in comparison to the ones with more complex shapes.

Testing and evaluation on location

The trail involved a small group of adults (2 women and 4 men, age 39–74); all of whom to some extent were involved in work related to archaeology, cultural heritage museums and/or public administration. Most of the participants had smartphones and were familiar with or owned an iPad. None of them were regular players of video games. When arriving close to the sites, a short introduction to the technology and the application was given to the participants. Then each of the users was given an iPad, the sitsim-application was activated and they started approaching the designated sites D2 and D7, thus using the app to actually locate and move to the sites. At the two sites they accessed the database information and tested other features in the app, such as 'Bird's view' to better observe the other sites in the area and how they were positioned in the landscape relative to the one they were actually visiting. The ruler for changing the sea level was constantly used to see how it related to the present site and others in the surrounding environment. The invited testers also accessed the archaeological databases online for the various sites exploring photos of artefacts, maps and written documentation. After the testing the participants answered a written questionnaire consisting of 16 questions.

In general, the feedback from the participants was very good and confirmed our previous experience with similar tests (Liestøl *et al.*, 2011). They quickly mastered the basic skills of operating the sitsim and found it easy to use. Some complained about a problem with the electronic compass, which in some cases caused the digital environment to drift sideways (a problem which now has been corrected). When asked about the added value of using the application on location they stressed the visualization of the sea level and how the various Stone Age sites were located in the landscape. This was considered a new and exciting experience, which they suggested could be deployed in a variety of contexts: excursions with school children, general mediation to the public at large (including senior citizens), as a valuable supplement to lectures etc. The possibility of accessing the online databases was also positively received, but it was noted that the layout needed adjustments to better accommodate the touch interface and the tablet screen. Asked how the simulation could be improved, several features were suggested: more detailed information about the findings, other types of relevant information, for example: vegetation, biology, fauna, natural resources, geology, narratives etc. It was also mentioned that the textures for vegetation could have more detail.

Conclusion and further research

Given the limited time and funding for developing the Krøgenes prototype the test showed that this is a promising deployment of Mobile Augmented Reality and the sitsim platform, and that it can enhance archaeological field work and mediation in various ways. In future versions we will focus on improving the detail of the terrain and the vegetation types, preferably by including 3D-models for trees, brush etc. It is also important to increase the number and positions of hypertext links to represent different kinds of information, not just one link for each excavated site, but related to location of individual artefacts, reconstructions of the excavation etc. We will also start work on how open data sets for terrain and vegetation can be accessed and exploited directly online, reducing the amount of manual adaptation required and thus extending the area which could be covered infinitely, in principle.

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